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Based on Multiattribute Utility:
An Illustration of Complex Utility Modeling

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AN ILLUSTRATION OF COMPLEX UTILITY MODELING

by

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Abstract

An application of multiattribute utility assessment to scale the
trauma severity of injuries to individuals is presented. Special attention
is given to problems not usually present or reported in applications of
the assessment techniques. These include nonmonotonic utility functions,
strong dependencies among attributes, and the state dependence of trauma
severity on age and existing diseases of the individual. The manner in
which these complexities were addressed is indicated.

AN INDEX OF TRAUMA SEVERITY BASED ON MULTIATTRIBUTE UTILITY:
AN ILLUSTRATION OF COMPLEX UTILITY MODELING

by

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In this paper we describe the elicitation of a multiattribute model
to represent a surgeon's professional judgments of the relative severity
of different physical injuries--trauma--suffered by patients. There are
three purposes:

1.   present an index for the severity of trauma

2.   indicate the usefulness of multiattribute utility models,
      which quantify values, for quantifying complex multiattribute
      professional judgments, and

3.   illustrate a complicated multiattribute assessment incorpora-
      ting state dependencies, nonmonotonic relationships, and complex
      interrelationships between variables.

To achieve these purposes, the paper is organized as follows. Section 1
defines the problem. This is structured in Section 2, where the set of
attributes developed to measure trauma severity are given. Section 3
provides the basic assessment of the severity index for a "healthy adult".
Since the severity of trauma is also dependent upon age and health, the
manner in which this state dependency is accounted for in the severity
index is indicated in Section 4. Section 5 discusses validation of the
index and Section 6 is the conclusion.

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1. THE PROBLEM

"Trauma", in the medical lexicon, is used to refer to physical injury to the body. Obvious to the layman is the fact that trauma may be found in various degrees and induced by varying types of events. A finger bruised by a hammer represents a lesser degree of trauma than does a broken leg, which in turn is less than extensive burns. A bump to the head may only cause a lump, but it may also cause unconsciousness, brain damage, or death. Hence, for evaluating medical facilities or medical procedures, allocating funds, creating or appraising operating policies of emergency medical facilities, and even triage, it should be worthwhile to develop a function that relates the multidimensional physical description of an injured person to the real numbers so that larger numbers represent a greater degree of trauma severity. We will call such a function a Trauma Severity Index (TSI).

A TSI has two concerns to represent. First, an injury may represent a threat to the life of the patient--a mortality threat. Second, the injury may represent a morbidity threat, i.e., have possible short and long term disability and discomfort associated with it. Construction of a TSI from objective data bases is hampered by having to take both considerations into account simultaneously (and degree of morbidity is in itself a highly judgmental quantity), and also impeded by the general lack of appropriate data bases. Thus, we have turned here to development of a TSI based on professional judgment. These judgments were modeled using an assessment procedure based on multiattribute utility. The assessment took place over a period of two days, and was somewhat unusual as it was conducted before a group of six to eight observers.

Background for the Assessment

The results reported here were a small part of the Severity Index Project funded by the National Center for Health Services Research, to investigate methods for development of judgment-based severity indexes. Severity indexes are needed as a control for different patient population

characteristics when evaluating performance of emergency medical services
at different institutions, in different regions, or at different times.
To the time of this assessment, the Severity Index Project had focused
on assessments made by panels of experts (Gustafson, Fryback, and Rose
[1981]), and had not examined the process with intensive, one-on-one
assessment with an individual physician. Working with an individual
physician would likely allow more attention to the detailed structure of
a severity index than was possible working within the context of a group
assessment.

Thus, one purpose of this present assessment was to compare the
results of a decision analyst (RLK) assessing a severity model of one
medical expert to working in a group format. It was felt that aspects
of the resulting index or procedures from the assessment may be relevant
to TSI panel assessments. The present paper addresses the assessment
process and methodological considerations in development of the multiattribute
model itself. The overall project results and comparison to panel
assessments are reported elsewhere (Gustafson, Fryback, and Rose [1981]).

Dr. Anthony Carnazzo, a trauma surgeon, agreed to be the medical
expert for the assessment procedure. Dr. Carnazzo, who was not directly
associated with the project but familiar with its design and goals, has
significant experience with the evaluation of emergency services. He is
President of Midlands Emergency Medical Services Council in Omaha,
Nebraska, and has served on a number of national panels and committees
designing and overseeing emergency services evaluation and development.

The assessment occurred over a 12-hour period, split into three
segments of approximately 4 hours each. The initial 4 hours was devoted
to structuring the problem of trauma severity sufficiently to lead to a
hierarchy of concerns and attributes to measure them. The analyst had
been briefed only superficially concerning the nature of trauma and

was not familiar with any of the medical terminology, so this initial period also served as a tutorial for him. Observers present were familiar with both utility assessment methodology and the medical circumstances of the assessment and occasionally helped as "translators" to ensure a common language was spoken during the assessment. By the end of the first morning session, the major areas of concern and candidate attributes for them were delineated. An afternoon session and a morning session on the following day were used to assess the multiattribute TSI model.

2. STRUCTURING TRAUMA

During the initial session a number of conventions and definitions were required to focus the TSI on a specific context, since the process of treating a trauma victim spans a considerable time and distance. The victim is injured somewhere, a means of conveyance is summoned, and the victim is transported to a receiving hospital where he/she may spend a few minutes to many hours in the emergency room. Depending upon the facilities and injury, the patient may die, be admitted to a general floor or a special facility of the hospital, transferred to another hospital, or be sent home.

Severity of the injury may change as a function of time and treatment, so our first convention concerned where in this process the trauma severity was to be assessed. We decided that the TSI would refer to the severity of the patient's condition at the moment he or she entered the emergency room door. Further, Dr. Carnazzo saw as the goal of treatment the preservation of life and minimization of residual morbidity. Thus the definition was narrowed further to be the severity of the trauma at the emergency room door given that optimal care were to be received, with the goal of treatment being as stated. The admixture of concern about mortality and morbidity in the assessment of severity was left to the professional judgment of Dr. Carnazzo.

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As a convention, we chose to scale the TSI from 0 representing no trauma to 1 representing the greatest level of trauma severity. The range of severity was chosen so a 0 level corresponds to a completely healthy individual and the 1 to an individual who will surely die very soon. Using a probabilistic utility assessment methodology (see, for example, Pratt et al. 1964), a TSI of 0.5 would correspond to a situation where an individual would have a 0.5 chance of being a fatality soon or otherwise being well soon with no residual morbidity. It may of course be rare that the mortality risk is so high and yet the residual morbidity is so low. Another circumstance corresponding to a 0.5 TSI level would be a patient with a 0.4 chance of dying, and if death did not occur there would be residual morbidity. Then, the 0.4 of the 0.5 TSI would account for mortality effects and the remaining 0.1 would correspond to the combined morbidity effects. Hence, the TSI level is always greater than the probability of mortality and the difference between the two numbers accounts for morbidity effects.

Major Trauma Concerns

Seven trauma concerns directly relating to the injury itself were identified. These were:

1. Ventilation Severity
2. Circulation Severity
3. Central Nervous System Severity
4. Internal Organ Injury Severity
5. Renal Function Severity
6. Muscular/Skeletal Severity
7. Burn Severity

Of course the human body is an interacting system within which these concerns represent interacting parts. Most trauma involves only one of these systems, but more than one may be involved with a very severe injury (a relatively rare event). A severe injury to any one of the systems represents a potentially lethal event.

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Many of these concerns required decomposition into more than one measure in order to indicate the trauma severity level. The hierarchy of concerns is shown in Figure 1. Ventilation, addressing whether the blood is being adequately oxygenated, is indicated by two measures, respiration rate and percent of total lung capacity unavailable due to lung collapse. Similarly, circulation severity is a function of pulse rate and mean blood pressure. Mean blood pressure itself is a composite variable indicated approximately by a weighted average of diastolic and systolic pressures.

Concern about the central nervous system is indicated by the level of function at which the patient is capable. Internal organ injury threatens immediate life from blood and function loss as well as residual morbidity. Renal function is potentially a direct cause of mortality and morbidity, but it also is an indicator of overall body function level. The major concern with musculoskeletal injury is major fractures, which lead to blood loss and shock.

Burns are rather difficult to handle. In fact there exists a severity index just for burns (Gustafson and Holloway [1975]). Here Dr. Carnazzo chose to represent burn severity as a function of two subconcerns, external surface burns (indicated by area of the burn and degree of the burn) and internal inhalation injury sometimes associated with the circumstances of burns.

Table 1 summarizes the measures finally chosen for each of the lowest-level concerns of Figure 1. The measures themselves are relatively straightforward for ventilation and circulation--these are the "vital signs" that most people are familiar with. The measure for Central Nervous System is the Glasgow Coms Score (GCS), a scale of brain and spinal cord injury (Langfitt [1978]), and is itself an additive combination

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Table 1. THE SEVEN TRAUMA CONCERNS AND ATTRIBUTES

Concern	Attributes	Range	Best	Worst
X_1=Ventilation	Respiration Rate	0-50/min	18+/-6	0
	Collapsed Lung	0-100%	0	100
X_2=Circulation	Pulse Rate	0-180/min	60-100	0
	Systolic Pressure	0-250 mm Hg	90-150	0
	Diastolic Pressure	0-140 mm Hg	60-100	0
X_3=Central Nervous System	Glasgow Coma Scale	3-15	15	3
X_4=Internal Organ	number needing surg. (liver, spleen, pancreas, kidneys, bowel, maj. vessel)	0-7	0	7
X_5=Renal Function	Urine Ouput	0-250 ml/hr	30-80	0
X_6=Muscular/ Skeletal	number of major fractures	0-8	0	0
X_7=Burns	% 1st degree	0-100% of body	0	100
	% 2nd degree	0-100% of body	0	100
	% 3rd degree	0-100% of body	0	100
	inhalation injury	0=no		
		1=yes	0	100

of four subscales relating to cognitive and motor function levels. Because there is a good deal of research relating the GCS values to mortality and morbidity risks, Dr. Carnazzo elected to use it as the single measure of brain and spinal cord severity.

In an effort to maintain relative simplicity of the TSI, it was determined that internal organ injury severity would be measured only by the number of organs requiring surgical repair, a number ranging from 0 to 7 (counting spleen, liver, pancreas, bowel, two kidneys, and any major vessel as the organs of interest). The number of fractures was considered to run from 0 to 8, as a simple count of the major bones/ structures fractured.

Complicating Factors

During discussion of the seven trauma concerns it became apparent that two other factors considerably affect the severity of trauma: the age of the victim and whether the patient had other major health problems at the time of the trauma. The discussion quickly led to the observation that the degree of assessed severity depends to a large extent on these two factors and that they combine with trauma in a complex way to affect total severity.

3.   ASSESSMENT OF THE TSI--HIGHLIGHTS

A number of features of the assessment are of interest as they represent situations not usually present or reported in multiattribute utility assessments. It is these that will be described here. Details for more standard assessment routines are found elsewhere (Keeney and Raiffa [1976], Keeney [1977]).

In appraising the general nature of the interrelationship between age and co-existing diseases and severity, Dr. Carnazzo agreed that

young or old age and other diseases would tend to increase the trauma
severity of any particular medical circumstance. He felt the relative
severity of any circumstance would roughly remain the same so age and
disease could act as an "adjustment" to a severity score computed for
the healthy 25 year old. Hence, the analyst decided during the assessment
process to obtain initial assessments for a patient representing the
optimum age, 25 years old, and optimum state of health (i.e., free of
other disease). The age and state of health would be dealt with as
discussed in Section 4 after a TSI for the healthy adult was obtained.

The discussion of age, disease and trauma indicates that the form
of the TSI could be represented by

$$S(x_1,\ldots,x_7,A,D) = f[A,D,S'(x_1,\ldots,x_7)] \tag{1}$$

where the final trauma severity scale S is a function of the seven
trauma concerns X_1, ..., X_7, listed in Table 1, age A, and coexisting
diseases D. The function S' is the "healthy 25 year-old" severity index,
and f is a function to be determined that adjusts $S'(x_1,\ldots,x_7)$ for A
and D. As a convention, we will refer to severity scales for each trauma
concern respectively as S_1, S_2, ..., S_7. Each of these will be scaled
from 0 (minimum severity) to 1 (maximum severity). From the description
above it should be clear that S_1, the ventilation severity scale, is
itself a function of two arguments, respiration rate and percent lung
collapse; S_2 is a function of pulse rate, diastolic pressure, and systolic
pressure; S_3, S_4, S_5, and S_6, are functions of single arguments corresponding
to the attributes in Table 1; and S_7, burn severity, is a function of
surface and inhalation burns.

From initial qualitative discussion it was apparent that S', the
combination of the seven concerns, would not be additive since very severe

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trauma due to any single concern resulted in a very severe overall picture. In fact, being at "1" severity on either S_7 (burn severity) or S_3 (central nervous system severity) alone was judged to rate an overall severity of 1 regardless of the levels of the other concerns. Further questioning revealed that a multiplicative utility function would probably be appropriate for S'. That is, S' may be expressed as

$$1 + kS'(x_1, \ldots, x_7) = (1+kk_1 S_1(x_1))(1+kk_2 S_2(x_2)) \ldots (1+kk_7 S_7(x_7), \qquad (2)$$

where k, k_1, k_2, ..., k_7 are constants (Keeney and Raiffa [1976]).

To order the k_is, we asked Dr. Carnazzo to specify the best and worst levels of each attribute, which are indicated in Table 1. Then we asked for a healthy individual (one with all best levels), which change to worst levels would result in the most severe trauma. The response was that the worst trauma would occur if either the central nervous system or burns were at their worst. The next worst was circulation, and so on. Hence, it was determined that the order of the constants, from largest to smallest, was $k_3 = k_7$, k_2, k_4, k_5, k_1, and k_6. Assessment of the individual S_i functions proceeded in this order.

Of interest in these assessments are three thing: a number of the single-attribute severity functions are nonmonotonic, the manner in which subscales for burn severity had to be developed and a problem with combining extremes of the different attributes and the manner in which this problem is circumvented.

Nonmonotonicity. Nonmonotonic functions such as respiration rate, urine output, pulse rate, and mean blood pressure, had to be assessed in two pieces. For example, respiration rate is optimum around 18 respirations per minute (or in the range 16 to 20). A respiration rate of less than 10 indicates poor oxygenation, and less than 5 per minute indicates real problems. On the other hand, respirations over (say) 30 per minute

indicate problems also as gas exchange begins to be abnormal at higher
and higher respirations and the high rate may indicate central nervous
system problems as well.

For the range 0 to 50 respirations per minute, Dr. Carnazzo felt 0
was the worst. Thus, the portion of the severity scale ranging from 0
respirations per minute to 18 per minute was assessed using the lottery
assessment procedure (Keeney and Raiffa [1976]). In a succession of
steps, a respiration rate was assessed that Dr. Carnazzo considered
equivalent to an equal probability of having either 0 or 18 respirations
per minute. The assessment questions were posed in terms of "likely
severity". For example, "Would you rather have a patient with a respiration
rate of 5 or one with a 50-50 chance of either a rate of 0 or 18?" The
certainty equivalent for this lottery was determined to be 8. Dr.
Carnazzo was then asked for a respiration rate between 0 and 18 that he
felt was equivalent in severity to the maximum respiration rate of 50.
This indifference level was also 8. In combination, these answers
determined a rough severity curve for respiration rate. To fill in the
severity curve and as consistency checks, certainty equivalents for
additional lotteries in both the upper and lower portions of the curve
were assessed.

Although it is possible to use curve fitting techniques to fit a
polynomial to represent the severity curve for the complex shape derived
from this set of judgments, we chose to approximate the curve with
straight-line segments for computerization of the severity model. This
technique was employed for all single-attribute severity functions. In
general, we would have liked to assess more carefully the single-attribute
functions using properties of the shapes of curves discussed in Pratt
[1964]. However, time available for the assessment forced this relatively
routine aspect of assessment to be dealt with in the more cursory manner
described.

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Nesting Submodels. Ventilation, circulation, and burns are each concerns that required more than one attribute to characterize them. Physiologically, a two-thirds to one-third weighted average of systolic pressure and diastolic blood pressure gives a good approximation of the average blood pressure. This additive combination, termed "mean pressure", was combined with pulse rate in a bilinear submodel (i.e., a two-attribute multiplicative model) to represent Circulation Severity S_2. The constants in the bilinear submodel were determined by solving simultaneous equations derived from indifference pairs involving mean pressures and pulse rates. Similarly, respiration rate and percent lung collapse were combined in a bilinear submodel to form Ventilation Severity S_1.

Of particular interest is the Burn Severity model. The surface burn severity is a function of the degree (or depth) of the burn, the percent of the body area covered, and whether burn inhalation injury occurred. At first, it was attempted to represent surface burns with two attributes, degree and percent of body area covered. But it is possible to have, say 15% second degree burn, and 40% first degree. Accordingly, three attributes, percent first degree, percent second degree, and percent third degree burns were used. Assessments indicated the relative severity of these surface burns did not depend on inhalation damage. Hence, separate severity functions illustrated in Figure 2a were assessed for each of these using lottery techniques. Then the series of four-dimensional indifference pairs in Figure 2b were obtained (the three dimensions for surface burns and the dichotomous "yes/no" inhalation injury dimension) from which we solved for the five constants in a multiplicative submodel.

The assessments in Figure 2 contained consistency checks which indicated the information was very consistent. This may partially be due to the fact that the overall burn severity is high if any attribute is bad. For instance, the severity of an individual with 100 percent third

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degree burns and no inhalation damage is essentially the same (i.e., 98 percent as severe) as an individual with 100 percent third degree burns and inhalation damage.

Combinations of Extremes of Attributes. Trauma severity described as combinations of the attributes is generally straightforward. To assure distinguishable consequences during assessments and for analytical convenience, combinations involving extreme levels of the attributes are often used to derive the various constants in a model with more than two dimensions. However, for the overall severity model (2), there are impossible combinations of the attributes--e.g., a patient with pulse of 0 and a mean blood pressure of 100.

Fortunately, scenarios with combinations of attributes near their extremes, although not common, were realistic. Thus, in the assessment process, Dr. Carnazzo was assisted in identifying conditions of these near-extreme levels, which in his judgment, corresponded to equal levels of severity. The severity levels of each were set equal to each other using (2) which provided an equation with the scaling constants as unknowns. After seven equations were developed, they were solved to provide the scaling constants in the severity model.

4. EFFECT OF AGE AND HEALTH STATUS OF THE PATIENT

Although age per se is not a factor in severity (i.e., an uninjured person should be regarded as zero on the TSI regardless of age!), it apparently acts as an influence and should be incorporated into the severity model. Dr. Carnazzo felt that the ages from adolescence to about 30 years old--all other things being equal--tend to have the most favorable prognosis for surviving major trauma. Below the age of 10-- and especially below about 2 years old--the ability to recover full potential appears to be somewhat less. And certainly as age increases, the resiliency of the body decreases.

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Similar consideration must be given to knowledge that the victim also suffers from co-existing disease(s). Dr. Carnazzo felt that four broad categories of disease covered the most important problems: hypertension, arteriosclerotic heart disease, diabetes, and chronic obstructive pulmonary disease. All other things equal, patients with these diseases are less able to withstand the damage of major trauma, and hence, the trauma was more severe.

Unfortunately, age and co-existing disease also interact, as the existence of hypertension in a very young person signals a very different disease threat than it does in a middle-aged person. Also, a 15 to 30 year old with even a combination of these diseases may be better able to withstand trauma than a "healthy" very young or very old person.

To model these features in the TSI, Dr. Carnazzo was asked to draw a curve whose height was proportional to the contribution of age to the determination of overall severity for an injury. The function s_A he drew is shown in Figure 3. This curve was checked roughly by assuming a moderate severity injury description using the various physical factors discussed so far, and obtaining conditional certainty equivalents in the age attribute.

Lastly, Dr. Carnazzo was asked to presume a set of patients with 50% third degree burns--a severely injured patient--with only the age and co-existing disease attributes varying. The combinations considered are shown in Table 2, where each cell represents a different patient. The age levels used were picked to include the near-extremes of the age attribute and two intermediate levels. These are assessed in combination with the five disease states which Dr. Carnazzo felt were the most significant. Although it was asking a good deal of work from him at the end of a very intense and lengthy assessment session, Dr. Carnazzo ranked all cells in the table from most to least implied severity with the

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Table 2. RANKED SEVERITY FOR AGE AND CO-EXISTING DISEASE
          (with 1 being the least severe)

	A=Age				
	4 mo.	2 yr	30 yr	55 yr	75 yr
No other diseases	16	3	1	2	4
hypertension	20	17	3	5	12
arteriosclerotic heart disease	18	13	4	6	13
chronic obstructive pulmonary disease	22	7	8	11	15
diabetes	21	19	9	10	14

D=Diseases

rank of "1" assigned to the least severe patient. The only enquiry about multiple co-existing disease concerned the effect of two or more of these at one time--Dr. Carnazzo replied that was hard to judge, but he'd estimate off the top of his head that the joint effect of two or more was a little less than the sum of the individual contributions.

From this matrix and careful review of the tape-recorded comments made during the course of the discussion concerning the influence on severity of disease and age, we estimated a severity influence function $s_{D/A}$ for co-existing disease __conditional__ on the age of the patient. These functions, which range from 0 to 1 just as s_A, are presented in Table 3. Conditional values for disease status in patients with inter- mediate ages are interpolated from the spanning columns in Table 3.

How much weight should be given to these two intervening variables? To get a sense of this Dr. Carnazzo was asked to compare the effect of changing age from best to worst to the relative effect on severity of urine output changing from best (50 cc/hr.) to worst (0 cc/hr.). He estimated the effect of age to be "a little better than half as much--call it 5/9 the effect of urine output." A similar estimate for the influence of associated disease was "8/9" as much as the effect of urine output.

Within the unadjusted severity model (2) based on the seven prime concerns, the effect of changing urine output from the least to the most severe level varies depending upon the overall severity level. The scaling factor k_5 for urine output was 0.36 indicating that if the severity with urine at its least severe level is S^+, the increase in severity due to changing urine output to its most severe level is given by $0.36(1-S^+)$. To see this, note that $S_5 = 0$ for the least severe level of urine output, so from (2), $1+kS^+ = (1+kk_1S_1) \ldots (1+kk_4S_4)(1+kk_6S_6) \ldots (1+kk_7S_7)$. At the most severe level of urine output, $S_5=1$ so from (2), $1+kS''=(1+kS^+)(1+kk_5)$ so the increase in severity is $S''-S^+= k_5 (1-S^+)$, since $k=-1$ as discussed in the text.

Accordingly, the maximum effect due to age is $(5/9)(0.36)(1-S^+)$ or $0.2(1-S^+)$. The actual increment to severity due to age is $0.2(1-S^+)s_A$,

Table 3. TABLE OF SEVERITY ADJUSTMENT FACTORS $s_{D/A}$ DUE TO OTHER DISEASES CONDITIONAL ON AGE OF THE PATIENT

D=Disease Combinations	A=Age				
	1/3 yr	2 yr	30 yr	55 yr	75 yr
None	0	0	0	0	0
HT[a]	.9	.8	.2	.2	.4
COPD[a]	.9	.6	.4	.4	.6
ASHD[a]	.9	.2	.6	.85	.9
DM[a]	.9	.9	.8	.8	.7
HT + COPD	1.0	1.0	.55	.55	1.0
HT + ASHD	.	.	.75	1.0	.
HT + DM	.	.	.98	.	.
COPD + ASHD	.	.	.98	.	.
COPD + DM	.	.	1.0	.	.
ASHD + DM	.	.	.	.	.
HT + COPD + ASHD	.	.	.	.	.
HT + COPD + DM	.	.	.	.	.
HT + ASHD + DM	.	.	.	.	.
COPD + ASHD + DM	.	.	.	.	.
HT + COPD + ASHD + DM	1.0	1.0	1.0	1.0	1.0

[a]HT = hypertension; COPD = chronic obstructive pulmonary disease; ASHD = arteriosclerotic heart disease; and DM = Diabetes Mellitus

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where the term s_A is determined by the curve in Figure 3. Thus the age adjusted trauma severity S^* is given by

$$S^* = S' + 0.2s_A(1-S'), \tag{3}$$

where S' is the severity of a 25 year-old with the same trauma.

Similarly the effect of associated diseases is incorporated in the TSI by adding to the age-adjusted severity an increment derived as a fraction of 8/9 of the maximum increment that could be attributed to changing urine output from best to worst. The maximum adjustment is then $0.32(1-S^*)$. The exact fraction $s_{D/A}$ of the maximum possible increment as a function of associated disease given age is determined by taking the appropriate number from Table 3 (interpolating between columns as necessary). The overall trauma severity from (1) is then given by

$$S = S^* + 0.32\ s_{D/A}(1-S^*). \tag{4}$$

Substituting (3) into (4) yields

$$S = S'[1-s(A,D)] + s(A,D), \tag{5}$$

where

$$s(A,D) = 0.2s_A + 0.32s_{D/A} - 0.064s_A s_{D/A} \tag{6}$$

In effect, the state dependence of trauma on age and diseases is shown by (5) with the term $s(A,D)$ characterizing that dependence.

Certainly there are other ways in which to model the effect of age and other diseases. Our approach was to preserve the qualitative and quantitative features discussed during the assessment at relatively minimum effort computationally.

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5. INDEX VALIDATION

Several comparisons may be made which are of direct interest in
verifying the properties of the TSI. In the course of the Severity Index
Project, Dr. Carnazzo had made direct ratings of 103 patients' severities
based on reading each patient's hospital chart. Dr. Carnazzo was one of
nine physicians who examined the charts, making a 0-100 severity rating
for each as part of the validation effort in the project (Gustafson,
Fryback, Rose [1981]). His direct ratings can be compared to the TSI
scores computed for the same 103 patients. For these 103 cases, the
correlation between Dr. Carnazzo's ratings and the TSI scores was .66.
Other severity indexes for trauma constructed in group assessment settings
by the Severity Index Project correlated with Dr. Carnazzo's ratings in
the range .6 to .7.

In a separate study, Dr. Carnazzo organized a data collection
effort at the Midlands Emergency Medical Services Council. He requested
that an interactive computer program for computing TSI scores be written
for use in his study. He reports 125 cases early in his series for
which there was a TSI score as well as a direct rating by a physician in
the Emergency Department as the patient was being treated. He has
computed two correlations for these cases (Carnazzo [1980]). For the
full TSI given by (5), the correlation with direct ratings was .66. If
only the seven-concern trauma score S' from (2) is used--i.e., before the
adjustment for age and other diseases--the correlation is .82.

Currently the TSI developed here is not being used. Other indexes
(Carnazzo [1980]; Gustafson, Fryback, Rose [1981]) apparently have
higher correlations with direct assessments and are much more simple to
use in application, being additive combinations of a few variables such
as blood pressure, pulse rate, respiration rate, and Glasgow Coma Score.

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We do not think this necessarily means the other severity scoring
systems are more valid than the one discussed here. Several issues
about validation of utility models are germane. The most critical,
granted that correlation is an appropriate measure of correspondence, is
whether one accepts direct, unaided judgments as the criterion standard.
There is reason not to accept such unaided judgments in a complex
judgment situation. Ample research has shown that humans are limited
information processors and that as a result they apparently ignore
information they say they would like to use, and they tend to process
with an additive form what information they do use (see, for example,
Dawes and Corrigan [1974]). Hence an index using a few of the most
critical variables and an additive combination rule probably would have
a high correlation with direct assessments.

Another issue is what would the assessor prefer to use to assess trauma
severity. An assessment such as the one reported here allows the expert
to transcend direct judgmental abilities by modeling situations where
critical underlying assumptions may be verified. Unfortunately, because
of the limited time, in the present case the assumptions were not all
tested. The model is on relatively solid ground for the basic seven con-
cerns. The adjustment for age and for other diseases was not as care-
fully assessed or supported by theory. It does appear to make sense,
even though apparently degrading ability of the TSI to replicate on-
the-spot assessments. One possible complication is that a physician in
the emergency room will in general not readily know about the diseases
the patient has, although age should be apparent.

6.   CONCLUSION

We have discussed a complicated assessment using methods of multi-attribute utility. Although the setting was not a utility problem, we believe the application is of interest in illustrating some problems in building complex models based on judgments.

In particular, we have noted problems with extremal points in the space that may simplify the determination of scaling constants, but may not make too much sense in the problem context. Also, we have shown extensive use of nested models to form a larger model. Of particular interest is the manner in which age and associated diseases were incorporated in the final model. This is an attempt to formalize a state dependent relationship, which retains the portions of the model utilizing well-known combining forms and yet includes in the model two considerations that affect severity in a complex fashion. Finally, we have raised issues in validation that will be of greater and greater importance as the art of multiattribute utility assessment advances into more complex realms.

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LIST OF FIGURE CAPTIONS

Figure 1: The Seven Main Concerns and Their Components

Figure 2: Assessments Used for the Burn Severity Index

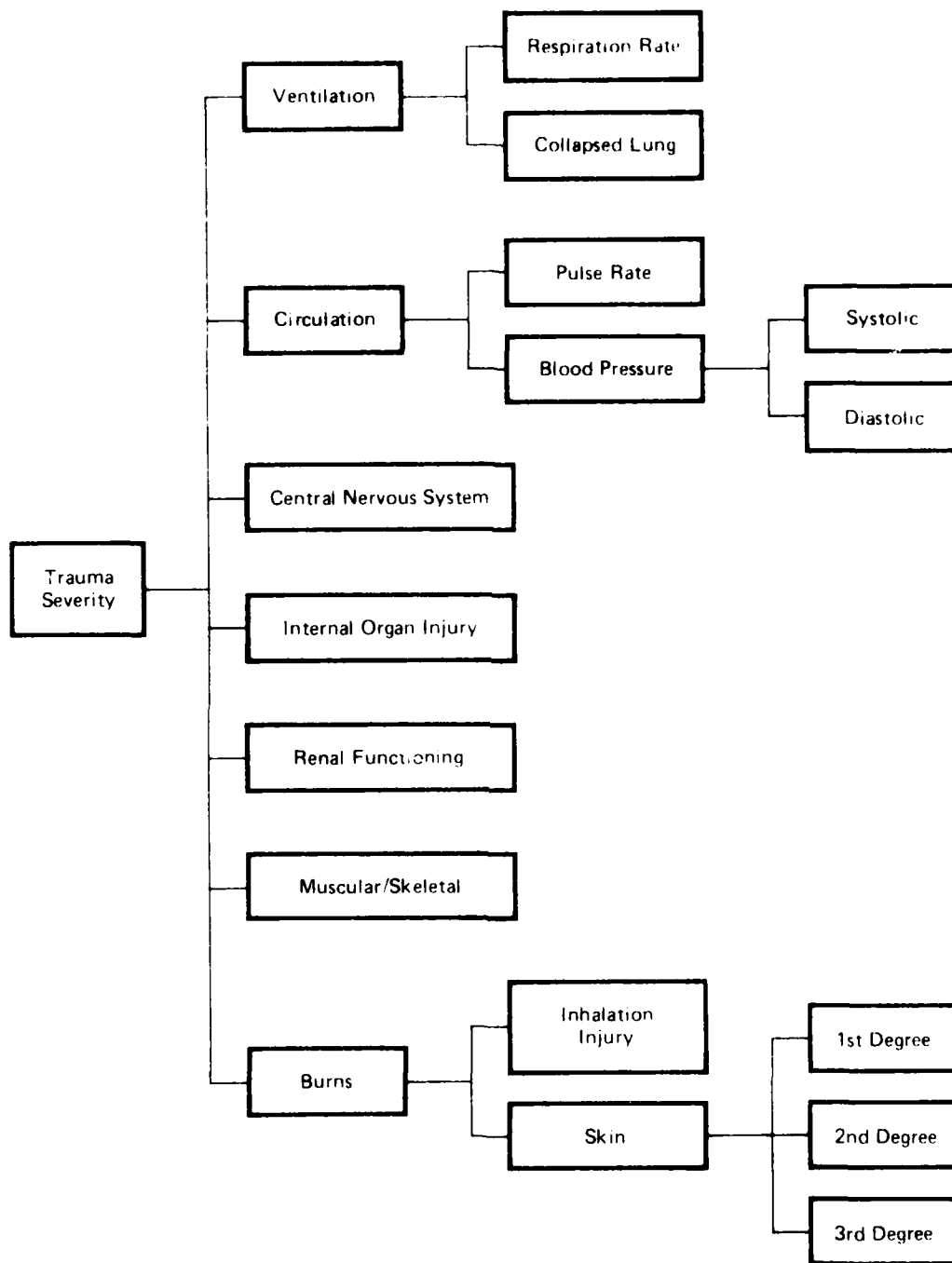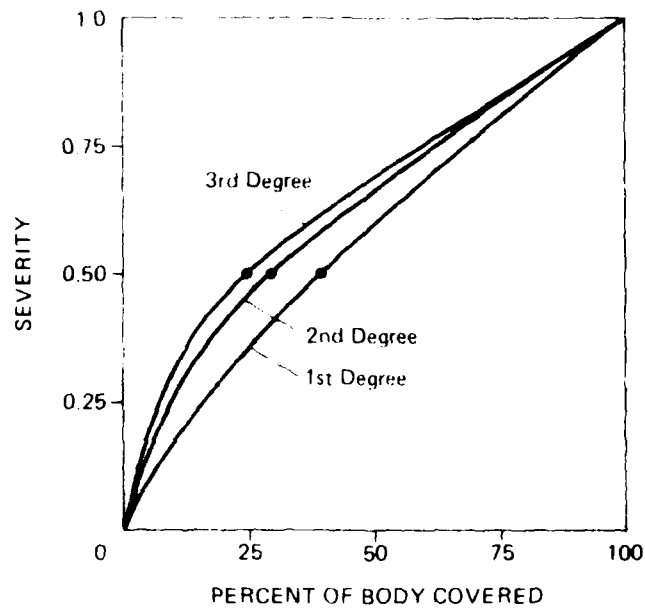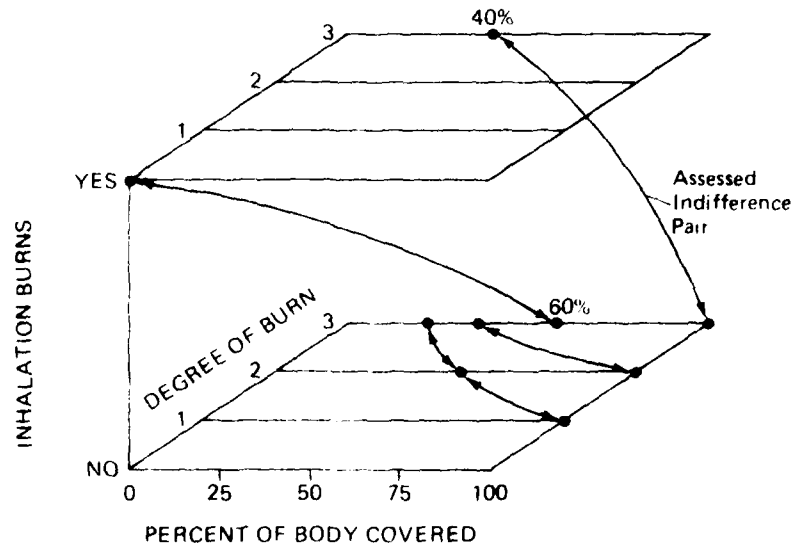Figure 3: The Severity Adjustment Factor s_A Due to Age

Figure 1. THE HIERARCHY OF TRAUMA SEVERITY CONCERNS

a. COMPONENT SEVERITY INDICES FOR SKIN BURNS

b. ASSESSED INDIFFERENCE PAIRS TO SPECIFY BURN
SEVERITY SCALING CONSTANTS

Figure 2. ASSESSMENTS USED FOR THE
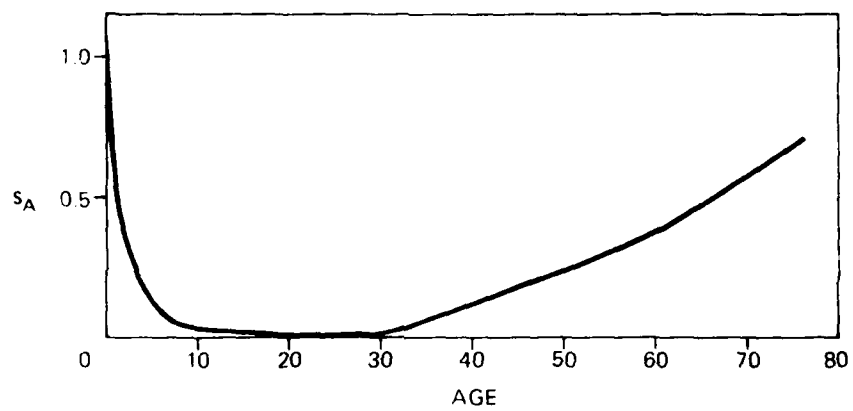BURN SEVERITY INDEX

Figure 3. THE SEVERITY ADJUSTMENT FACTOR s_A DUE TO AGE

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